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(54) Title: SPECTRALLY BEAM COMBINED DISPLAY SYSTEM
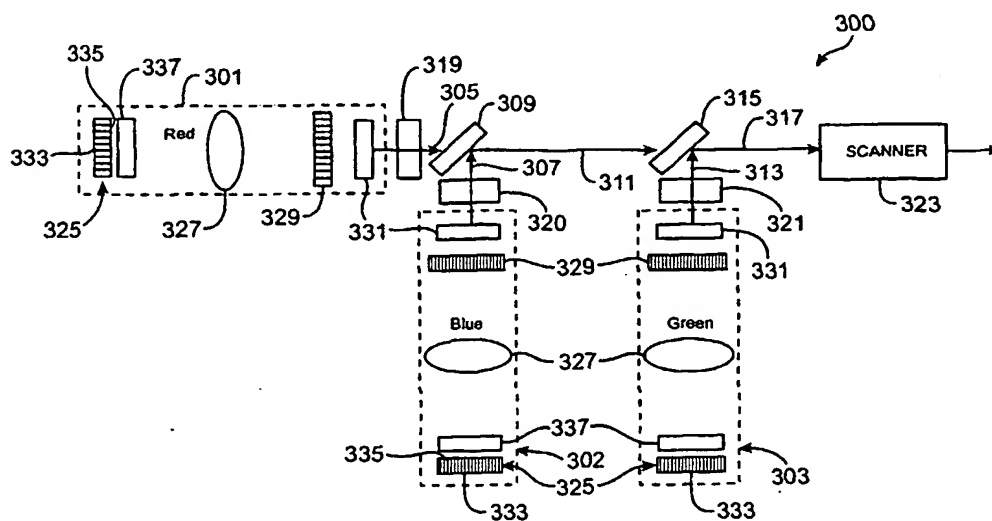
(57) Abstract: A method and apparatus for generating a display is provided with each color of the display is generated by incoherently combining the beams of tens or hundreds of individual lasers. In order to achieve a full color display, three independent incoherently beam combined (IBC) systems (301, 302, 303) are used to generate the required three colors (e.g., red, blue, green). The output from each IBC system is modulated and the three beams are combined to form a single, modulated output beam that is directed to a display scanner (323).

Spectrally Beam Combined Display System

5   CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of provisional patent application Serial No. 60/290,135 filed May 9, 2001, the disclosure of which is incorporated herein by reference for all purposes.

FIELD OF THE INVENTION

10   The present invention relates generally to incoherent beam combining and, more particularly, to a method and apparatus for generating a color display.

BACKGROUND OF THE INVENTION

There is an increasing demand for large-screen information displays, both as data displays and entertainment sources. While rapidly developing plasma displays

15   can fill some niches, front and rear projection systems are still the primary means used for those applications requiring a large screen. Projection-based display systems can be realized in several different ways and can utilize CRTs, liquid-crystal image plates or multipixel arrays.

One method of achieving a very bright, high resolution display is to scan a

20   modulated laser beam across the display screen. The technology for scanners and modulators has developed rapidly in the last several years with micro-optical-mechanical systems (MOEMS) and micro-electro-mechanical systems (MEMS) demonstrating very high performance. The development of suitable laser sources, however, has lagged behind these developments in scanner/modulator technology, remaining both overly

25   complicated and expensive. At least in part, the difficulties of utilizing lasers in display devices has been due to the inadequate power, beam brightness, color and durability of typical wavelength-converted solid-state lasers.

To date, diode lasers have been the simplest and lowest cost source for laser-based display systems. Unfortunately, green and blue diode lasers are not widely

30   available nor do they produce sufficient power. For example, diodes emitting in the red

wavelength band are available but produce only a few tens of milliwatts. Even worse, the green and blue diode sources under development have only been demonstrated with power levels of a few milliwatts. On the other hand, display applications typically require between 500 milliwatts and 5 watts of output power at all three primary colors.

5   Accordingly, what is needed in the art is a display system capable of high brightness and resolution using high power, inexpensive, durable laser sources capable of operating at the desired red, green and blue wavelengths. The present invention provides such a system.

SUMMARY OF THE INVENTION

10   The present invention provides a method and apparatus for generating a display. In the disclosed system, each color required by the display is generated by incoherently combining the beams of tens or hundreds of individual lasers, thus providing sufficiently high output for large displays. Additionally, as the lifetime of a diode laser is an inverse function of its output power, utilizing a large number of lasers for each color

15   source increases the operating lifetime of the system since the individual lasers operate at relatively low powers.

           Each incoherently beam combined (IBC) system used in the present invention is comprised of a plurality of gain elements/emitters. The individual IBC cavities are formed by the combination of a high reflectance (HR) coating applied to the

20   back facets of the gain elements/emitters and an external output coupler. Within each IBC cavity is a wavelength dispersive element, such as a diffraction grating, as well as a collimating optic. The front facets of the gain elements/emitters are coated with an anti-reflection (AR) coating, thus insuring that the external cavity sets the lasing wavelength of the individual gain elements/emitters. Preferably within each IBC cavity is at least

25   one optical element that reduces the divergence of the individual gain elements/emitters in the fast axis while having minimal impact on the divergence in the slow axis.

           In one embodiment of the invention, three independent IBC systems are used to generate the three colors (e.g., red, green and blue) necessary for a full color display. The output from each IBC system is modulated and the three beams are

30   combined, for example using dichroic beam splitters, to form a single, modulated output beam. The single output beam is then directed to a scanner that generates the display. In one configuration the scanner is an x-y scanner, thus generating the display by scanning a

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single output beam across the display. In another configuration , the scanner is a one dimensional scanner, this type of scanner being used when the modulated IBC system creates an entire row or column of the desired display.

5   In another embodiment of the invention, the three IBC systems required for a full color display utilize a common output coupler. This system can be used to reduce the overall system size and complexity, thus further reducing cost. Although a single collimating optic can be used, preferably each IBC system uses a dedicated collimating optic, thus achieving diffraction limited output with simple spherical optics.

          In another embodiment of the invention, each IBC system utilizes a beam
10   combining plate to incoherently combine the outputs of a plurality of emitters (e.g., single, transverse mode edge emitters). The emission of each individual emitter passes through a collection/collimating optic, a prism and a wavelength separating element prior to entering the beam combining plate. In at least one embodiment, the wavelength separating elements (e.g., dielectric coating, holographic grating, etc.) are deposited
15   directly onto an exterior surface of the beam combining plate.

          A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

20   Fig. 1 is a schematic illustration of an IBC laser system according to the prior art;

              Fig. 2 is a schematic illustration of an IBC laser system such as that illustrated in Fig. 1 with the inclusion of an additional lens element;

              Fig. 3 is an illustration of one embodiment of a multi-color display system
25   in accordance with the invention;

              Fig. 4 is an illustration of an alternate embodiment of a spectrally beam combined source for use in a display system;

              Fig. 5 is an illustration of an alternate embodiment utilizing a single output coupler for all three colors that is compatible with diffraction limited output and simple
30   spherical optics;

              Fig. 6 is an illustration of an embodiment similar to that provided in Fig. 5 except that reflective collimating optics are used;

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Fig. 7 is an illustration of an alternate IBC laser system for use in a display system such as that shown in Fig. 3;

Fig. 8 is an illustration of an alternate source utilizing VCSELs; and

Fig. 9 is an illustration of a plurality of systems such as that shown in Fig.

5   8 incoherently beam combined using a non-free space IBC system such as that shown in Fig. 7.

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

Fig. 1 schematically illustrates an IBC laser system 100 in accordance with the prior art. System 100 includes an array 101 comprised of a plurality of individual

10   gain elements or emitters 103, all with nominally the same center wavelength. Emitters 103 can be edge emitting diodes, vertical-cavity surface emitting lasers (VCSELs), vertical external cavity surface emitting lasers (VECSELs), diode-pumped solid-state lasers, or other types of lasers. The back facet of each emitter 103 is coated with a high reflectance (HR) coating 105 while the front facet of each emitter 103 is coated with an

15   anti-reflection (AR) coating 107. AR coating 107 insures that the external cavity sets the lasing wavelength by preventing coupled cavity, etalon effects. The optical cavity is formed by the combination of high reflectance coatings 105 and a single external output coupler 109.

Located within the external optical cavity of IBC laser system 100 is a

20   wavelength dispersive element 111. As shown, wavelength dispersive element 111 is a reflective diffraction grating. It is understood that other types of dispersive elements, including both reflective and transmissive elements, can also be used within system 100. Dispersive element 111 forces each of the individual elements of array 101 to operate at a distinct wavelength, thus allowing laser system 100 to output a relatively broad

25   bandwidth.

Also located within the external optical cavity is a lens 113. Lens 113 collects and collimates the light from each emitter 103, directing the light onto dispersive element 111. It is understood that a reflective collimating optic can also be used within system 100. Typically array 101 is located at approximately one focal length distance

30   from lens 113.

Differentiation of the grating equation yields

$$\Delta\lambda = d \ (W_{array}/f) \cos (\theta_G)$$

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where $\Delta\lambda$ is the bandwidth of the IBC laser, d is the grating line spacing, W_{array} is the width of the laser gain element array, f is the collimation optic focal length, and θ_G is the incident angle on the grating. This equation shows that the bandwidth of the IBC laser is directly related to the focal length of the collimating optic, the grating grove spacing, and

5   the array width. Accordingly the bandwidth of such a laser, unlike a more conventional laser, can be optimized for a specific application.

Although the bandwidth of an IBC laser can be optimized for different applications, there are a number of design considerations that must be taken into account when using a gain element array consisting of single transverse mode, edge-emitting

10   semiconductor lasers. First, the resonator must be astigmatic in order to mode match the output of the semiconductor lasers. Mode matching is required to insure operational efficiency. Second, the system must be designed to minimize aberrations, a difficult optical design task due to the large emission angles involved and due to the divergence angle within the plane which is perpendicular to the array (i.e., the fast axis) being

15   different from that within the plane which is parallel to the array (i.e., the slow axis). For this type of emitter, the F-number for the fast axis is typically about F/1 while the F-number for the slow axis is typically about F/3. Additionally, as the resonator optics must operate at F/3 over a field angle defined by the ratio of the bar width to the focal length, this design task becomes increasingly more difficult as the array width is increased.

20   Assuming a single spherical optic (i.e., simple spherical mirror or thin lens) as shown in the prior art and as illustrated in Fig. 1, and assuming an emitter slow axis F-number of F/3, spherical aberration limits the maximum useable focal length of lens 113 to approximately 25 millimeters. Coma limits the maximum diode bar length to approximately 1.3 millimeters. At an emitter wavelength of 1500 nanometers, diode

25   arrays can be custom manufactured with a linear power density of 5 Watts per centimeter. With a 1.3 millimeter bar width, and assuming 100 percent cavity efficiency, the maximum achievable IBC laser power in this design is 0.8 Watts.

Power scaling for a conventional IBC laser system can be achieved through the use of a large lens group. Due to the divergence of the fast axis, this lens

30   group must perform at F/1 on axis without introducing aberrations. Furthermore, it must be able to operate over the slow axis field angle at F/3 without introducing aberrations. As a result of these requirements, the lens group must use large optics with custom radii

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and highly aspheric surfaces. Such a design does not lend itself to compact packaging or inexpensive optics.

Fig. 2 is a schematic illustration of an alternate IBC optical system as disclosed in co-pending U.S. Patent Application Serial No. 09/690,233, the disclosure of which is incorporated herein for any and all purposes. IBC optical system 200 is the same as system 100 except for the inclusion of a lens or lens array 201 located between array 101 and lens 113. Preferably lens 201 is immediately adjacent to the AR coated facets of emitters 103. Lens 201 reduces the divergence of emitters 103 thus allowing laser array 101 to be much wider, or alternately, to be comprised of multiple individual arrays, while maintaining a relatively simple resonator optical design. As a consequence, much higher output powers and/or narrower bandwidths can be achieved without utilizing an exceedingly complex optical design.

As disclosed in co-pending U.S. Patent Application Serial No. 09/690,233, lens 201 can be comprised of a fast cylindrical lens that reduces the divergence of the light emitted by emitters 103 in the fast axis while having negligible impact on the divergence of the light in the slow axis. Preferably the divergence in the fast axis is reduced to match that of the slow axis, thereby relaxing the on-axis F-number requirements of the cavity optics to those of the slow axis. Alternately, lens 201 can be comprised of a plurality of individual lens elements, each lens element acting upon the emissions of a single emitter 103. By reducing the divergence of each emitter 103, and preferably reducing the divergence of the fast axis such that it substantially matches the divergence of the slow axis, the field angle over which the remainder of the cavity optics must operate is greatly increased. Alternately, lens 201 can be comprised of a fast cylindrical lens used in combination with a plurality of lens elements, the lens elements having a center-to-center spacing matching that of emitters 103. Preferably the fast cylindrical lens reduces the divergence of the light in the fast axis and has negligible effect on the light divergence in the slow axis while the individual lens elements, each of which is a cylindrical lens, reduces the divergence of the light emitted by emitters 103 in the slow axis and has negligible effect on the divergence of the light in the fast axis. By combining the effects of the fast cylindrical lens with the array of lens elements, the astigmatism of the edge emitters is corrected. Alternately, lens 201 can be comprised of a plurality of lens elements configured in an array, each lens element being an aspheric lens having a different focal length in the fast and slow axes.

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Fig. 3 is an illustration of one embodiment of a multi-color display system 300 in accordance with the invention. System 300 preferably includes three different IBC optical systems, 301-303, thus providing three individual colors and the accompanying capability to support a full color display. As shown, optical system 301 provides a red

5 source (preferably with a center wavelength of approximately 630 nanometers), optical system 302 provides a blue source (preferably with a center wavelength of approximately 470 nanometers), and optical system 303 provides a green source (preferably with a center wavelength of approximately 530 nanometers). Output beam 305 of source 301 is combined with output beam 307 of source 302 using a first dichroic beam splitter 309.

10 Combined beam 311 is combined with output beam 313 of source 303 using a second dichroic beam splitter 315 to form a three-color output beam 317.

In order to use output beam 317 in a display system, each individual color must be modulated. Accordingly, modulators 319-321 are used with optical systems 301-303, respectively. Three-color output beam 317, comprised of the three modulated output

15 beams, is directed to a scanner 323 (e.g., an x-y scanner), scanner 323 directing the modulated three-color beam at the display means (e.g., screen). Scanning systems as well as laser source modulators, both external cavity and intra-cavity modulators, are well known in the art and will therefore not be described in detail herein. In an alternate embodiment, modulation of the intensity of the individual laser sources is accomplished

20 by modulating the current to each diode bar.

In the embodiment shown in Fig. 3, each IBC optical system 301-303 is comprised of an emitter/gain element array 325, a collimating optic 327, a wavelength dispersive element 329 and an output coupler 331. The optical cavity of each IBC optical system is formed by the combination of output coupler 331 and HR coatings 333 applied

25 to the back facets of the individual emitter/gain elements of array 325. AR coatings 335 insure that the external cavity sets the lasing wavelengths. Preferably, and as previously disclosed, one or more optical elements 337 are interposed between each array 325 and each collimating optic 327 in order to reduce the divergence of the individual emitter/gain elements.

30 It is understood that the individual elements of each IBC optical system 301-303 can be changed without departing from the invention. For example, and as previously discussed in detail, array 325 can be comprised of various different emitter/gain element types, collimating optic 327 can be either reflective or transmissive,

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and wavelength dispersive element 329 can be either reflective or transmissive. It is also understood that the three IBC optical systems need not utilize identical configurations. For example, IBC optical systems 301 and 302 may be transmissive systems as shown, while IBC optical system 303 may be a reflective or partially reflective system (e.g.,

5   using a reflective dispersive element and/or a reflective collimating optic).

Fig. 4 is an illustration of an alternate embodiment of a spectrally beam combined source for use in a display system. In this embodiment, several of the optical elements are common to each of the separate, single color IBC systems, thus providing a simplified overall system with size, design complexity and cost benefits. For the sake of

10   drawing simplicity, only a red source 401 and a green source 403 are shown. It will be appreciated that an additional source (e.g., a blue source) can be added to source system 400, thus achieving a three-color system.

As shown in Fig. 4, the emissions from the individual emitter/gain elements of each array 401 and 403 preferably pass through one or more lens elements

15   405 that reduce the divergence of the individual emitter/gain elements. In this embodiment, a single collimating optic 407 is used to collect and collimate the light from each emitter of both arrays (or from all three arrays for a three-color system), directing the light onto a single dispersive element 409. The optical cavity of each IBC optical system is formed by the combination of a single output coupler 411 and HR coatings 413

20   and 415 applied to the back facets of the individual emitter/gain elements of arrays 401 and 403, respectively. AR coatings applied to the front facets of the individual emitter/gain elements insure that the external cavity for each of the IBC optical systems sets the lasing wavelengths for the individual emitter/gain elements of each specific IBC system. It will be appreciated that both collimating optic 407 and dispersive element 409

25   can be either reflective or transmissive.

As in the embodiment illustrated in Fig. 3, the system output beam 417 is directed to a scanner 323, scanner 323 directing the output beam onto a screen or other display means. In this embodiment, preferably modulation of the intensity of each color is achieved by modulating the current to the individual arrays. Alternately, intra-cavity

30   modulators can be used.

A disadvantage of the embodiment illustrated in Fig. 4 is that the optical system, and in particular collimating optic 407, must operate over very large field angles. As a result, aberrations are introduced that limit the applicability of the system with

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respect to certain display systems (e.g., high definition systems). The requirement for large field angles is driven by the required spatial separation, Δx, between arrays. For example, assuming a typical focal length of 10 to 20 centimeters for collimating optic 407, and given that Δx is on the order of 1 to 2 centimeters for a typical set of parameters,

5   the minimum working field angle is about one tenth of a radian (i.e., approximately 5 degrees). This angle is quite large if diffraction limited output power is desired and, as a result, prohibits the use of simple spherical collimation optics.

Fig. 5 is an illustration of an alternate embodiment utilizing a single output coupler for all three colors that is compatible with diffraction limited output and simple

10   spherical optics. As in the previous embodiment, multiple arrays 501-503 are used with a single wavelength dispersive element 505 and a single output coupler 507. However, in this embodiment each array 501-503 has a dedicated collimating optic 509-511, respectively, thus allowing a large angular shift to be introduced between adjacent arrays (e.g., angular shift 513 between arrays 501 and 502 and angular shift 515 between arrays

15   502 and 503). Assuming a difference in wavelength between adjacent arrays of approximately 100 nanometers, a typical angular shift is on the order of 10 degrees. The large angular shifts allow the arrays to be widely separated without introducing large off-axis operating angles. In this embodiment the optics for each array operate at the same maximum field angle which is set by the width of each array and the focal length of the

20   associated collimating optic. As an example, assuming a 2 millimeter long array, the field angle is less than 0.5 degrees. This field angle allows diffraction limited beam quality to be maintained while utilizing simple spherical optics.

Fig. 6 is an illustration of an embodiment similar to that provided in Fig. 5 except that transmissive collimating optics 509-511 are replaced with a reflective surface

25   601. It is understood that although a single reflective, collimating optical surface 601 is shown in Fig. 6, a similar configuration could be used wherein each array utilizes a dedicated reflective, collimating optic. In this embodiment the beams must be shifted to prevent the arrays from obstructing the beams. As a result of this shift, a small amount of off-axis aberration out of the plane of the figure is added.

30   As in the prior embodiments, the output from output coupler 507 is directed to a scanner 323, scanner 323 directing the output beam onto a screen or other display means. As previously noted, intensity modulation for each color is achieved

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either by modulating the current of the individual arrays or through the use of intra-cavity modulators.

Fig. 7 is an illustration of an alternate IBC laser system 700. It is understood that IBC laser system 700 is approximately equivalent to one of the IBC

5   systems, 301-303, illustrated in Fig. 3. Accordingly, a three-color display system utilizing IBC laser system 700 would still require two other sources, preferably similar in configuration to system 700, in addition to individual color modulators and a scanner.

System 700 utilizes a diode bar 701 comprised of a plurality of single, transverse mode edge emitters 703. The output from each emitter 703 is collected and

10   collimated with an optical element 705 prior to passing through a prism 707. Although a plurality of individual optical elements 705 and individual prism elements 707 are shown for the sake of simplicity, the inventors expect that an array of optical elements 705 and an array of prism elements 707 would be used, wherein the center-to-center spacing of the individual elements 705 and individual prisms 707 are equivalent to the center-to-center

15   spacing of emitters 703.

The throughput for each prism 707 is directed at an individual wavelength separating element 709. Each wavelength separating element 709 is comprised of either a dielectric coating or a holographic grating and is designed to transmit the wavelength of the corresponding emitter while reflecting the wavelengths that correspond to those

20   emitters that are positioned further from output coupler 711. For example, in the embodiment provided in Fig. 7, the first wavelength separating element 709 (indicated on Fig. 7 with a "1") is designed to transmit λ_1 while reflecting λ_2, λ_3...λ_N; the second wavelength separating element 709 (indicated on Fig. 7 with a "2") is designed to transmit λ_2 while reflecting λ_3, λ_4...λ_N; the N-1 wavelength separating element 709 is

25   designed to transmit λ_{N-1} while reflecting λ_N; and the Nth wavelength separating element 709 is designed to transmit λ_N.

In this embodiment of an IBC system, and as illustrated in Fig. 7, preferably the wavelength separating elements 709 are affixed to a beam combining plate 713. In the preferred embodiment, the wavelength separating elements 709 are deposited

30   directly onto a surface 715 of beam combining plate 713. As illustrated, the beams from the individual emitters are combined in beam combining plate 713 rather than in free space as in the previously described IBC systems. An advantage of this embodiment is

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that each IBC system used to generate each individual color of the display system can be quite compact. Additionally, the various components (e.g., array, lens array, prism array, wavelength separating elements, beam combining plate) can be bonded together into a single unit (or a system comprised of only a few units), thus forming a very robust

5   system.

Fig. 8 is an illustration of an alternate source 800 utilizing VCSELs. As shown, source 800 is comprised of a plurality of VCSEL lasers 801, the individual VCSELs being either optically or electrically pumped. VCSELs 801 are arranged in a row and coupled to a beam combining element 803 which includes a reflective surface

10   805 such that their output beams coherently sum at a single wavelength.

A plurality of sources 800 can be incoherently combined using either the free space or the non-free space techniques described above, thus forming individual IBC systems for each color. For example, Fig. 9 illustrates a plurality of systems 800 that are incoherently beam combined using the internal (i.e., non-free space) system 700.

15   Alternately, a plurality of systems 800 can be incoherently beam combined using a system such as that illustrated in Figs. 1 and 2. Once combined, the output beams from three such systems (e.g., one system producing red, one system producing green, and one system producing blue) are individually modulated, combined, and directed at a suitable scanner as previously described.

20   In addition to the embodiments described above, it will be appreciated that the disclosed three-color IBC sources are applicable to a wide range of modulator and scanner configurations and those provided above are only meant to be illustrative, not limiting, of the scope of the invention. For example, a variety of microelectromechanical systems (MEMS) are currently under investigation for use in displays. In at least some

25   embodiments of these systems, three-color sources (e.g., red, green and blue LEDs) are used as the light input, the MEMS devices reflecting or refracting the light towards a scanner or directly at the screen. Such MEMS devices include, for example, digital micromirror devices (DMD) and grating light valve (GLV) devices.

In one MEMS based embodiment a three-color IBC system, such as those

30   illustrated in and described with reference to Figs. 3-6, is used in conjunction with a GLV device. The three-color IBC system illuminates a single pixel as defined by the GLV device. Preferably each color of the three-color IBC system is pulsed at a set frequency (e.g., red-green-blue-red-green-blue, etc). Modulation of the GLV device in timed

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combination with the pulsed colors yields a modulated pixel that can then be scanned to 'paint' an image on the display. Alternately, each of the three output beams from the three-color IBC system can be slightly offset from one another, each output beam (and color) corresponding to a portion of the single GLV pixel. In this configuration the three

5   individual IBC systems are not pulsed, rather the color of the pixel is determined by the state of the respective red, green, and blue portions of the GLV device. Alternately, three-color IBC systems can be used to form a linear array of individual three-color pixels. This three-color IBC array, used in conjunction with a GLV array, provides one row or column of the desired display. Scanning the row or column with a one-

10   dimensional scanner (e.g., a galvanometric mirror that scans vertically or horizontally) allows the formation of a two-dimensional image. Alternately, three IBC arrays, each dedicated to a specific color (e.g., red, green and blue) can be used in conjunction with three GLV arrays, dedicated to red, green and blue channel modulation, and a one-dimensional scanner to provide a three-color display.

15 .   As will be understood by those familiar with the art, the present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Accordingly, the disclosures and descriptions herein are intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

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WHAT IS CLAIMED IS:

1   1.   A three-color, light projection system, comprising:

2   a first incoherently beam combined (IBC) laser system outputting a first

3   color beam;

4   a first means for modulating said first color beam;

5   a second IBC laser system outputting a second color beam;

6   a second means for modulating said second color beam;

7   a third IBC laser system outputting a third color beam;

8   a third means for modulating said third color beam; and

9   a means for scanning said modulated first, second and third color beams.

1   2.   The three-color, light projection system of claim 1, said first IBC

2   laser system further comprising:

3   a first plurality of gain elements, wherein each of said gain

4   elements is further comprised of both a back facet and a front facet;

5   a first plurality of high reflectance (HR) coatings on said back

6   facets of said first plurality of gain elements;

7   a first plurality of anti-reflection (AR) coatings on said front facets

8   of said first plurality of gain elements;

9   a first output coupler;

10   a first wavelength dispersive element interposed between said first

11 plurality of gain elements and said first output coupler; and

12   a first collimating means interposed between said first plurality of

13 gain elements and said first wavelength dispersive element;

14   said second IBC laser system further comprising:

15   a second plurality of gain elements, wherein each of said gain

16 elements is further comprised of both a back facet and a front facet;

17   a second plurality of HR coatings on said back facets of said

18 second plurality of gain elements;

19   a second plurality of AR coatings on said front facets of said

20 second plurality of gain elements;

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21   a second output coupler;

22   a second wavelength dispersive element interposed between said

23 second plurality of gain elements and second first output coupler; and

24   a second collimating means interposed between said second

25 plurality of gain elements and said second wavelength dispersive element;

26   said third IBC laser system further comprising:

27   a third plurality of gain elements, wherein each of said gain

28 elements is further comprised of both a back facet and a front facet;

29   a third plurality of HR coatings on said back facets of said third

30 plurality of gain elements;

31   a third plurality of AR coatings on said front facets of said third

32 plurality of gain elements;

33   a third output coupler;

34   a third wavelength dispersive element interposed between said

35 third plurality of gain elements and said third output coupler; and

36   a third collimating means interposed between said third plurality of

37 gain elements and said first wavelength dispersive element.

1   3.   The three-color, light projection system of claim 2, wherein said

2 first, second, and third pluralities of gain elements are selected from the group consisting

3 of edge emitting diodes, vertical-cavity surface emitting lasers (VCSELs), vertical

4 external cavity surface emitting lasers (VECSELs), and diode-pumped solid-state lasers.

1   4.   The three-color, light projection system of claim 2, wherein said

2 first, second, and third wavelength dispersive elements are selected from the group

3 consisting of reflective wavelength dispersive elements and transmissive wavelength

4 dispersive elements.

1   5.   The three-color, light projection system of claim 2, wherein said

2 first, second, and third collimating means are selected from the group consisting of

3 reflective collimating means and transmissive collimating means.

1   6.   The three-color, light projection system of claim 2, said first IBC

2 laser system further comprising a first divergence reducing means interposed between

3 said first plurality of gain elements and said first collimating means, said second IBC

4 laser system further comprising a second divergence reducing means interposed between

5 said second plurality of gain elements and said second collimating means, and said third

6 IBC laser system further comprising a third divergence reducing means interposed

7 between said third plurality of gain elements and said third collimating means.

1   7.   The three-color, light projection system of claim 6, wherein said

2 first, second, and third divergence reducing means are selected from the group consisting

3 of cylindrical lenses, lens arrays, cylindrical lenses used in combination with lens arrays,

4 and aspheric lens arrays.

1   8.   The three-color, light projection system of claim 6, wherein said

2 first divergence reducing means reduces a fast axis divergence corresponding to said first

3 plurality of gain elements to substantially match a slow axis divergence corresponding to

4 said first plurality of gain elements, wherein said second divergence reducing means

5 reduces a fast axis divergence corresponding to said second plurality of gain elements to

6 substantially match a slow axis divergence corresponding to said second plurality of gain

7 elements, and wherein said third divergence reducing means reduces a fast axis

8 divergence corresponding to said third plurality of gain elements to substantially match a

9 slow axis divergence corresponding to said third plurality of gain elements.

1   9.   The three-color, light projection system of claim 2, wherein said

2 first modulating means modulates a current corresponding to said first plurality of gain

3 elements, wherein said second modulating means modulates a current corresponding to

4 said second plurality of gain elements, and wherein said third modulating means

5 modulates a current corresponding to said third plurality of gain elements.

1   10.   The three-color, light projection system of claim 1, wherein at least

2 one of said first, second and third modulating means utilizes a grating light valve (GLV).

1   11.   The three-color, light projection system of claim 1, wherein said

2 first modulation means is a first GLV, wherein said second modulation means is a second

3 GLV, and wherein said third modulation means is a third GLV.

1   12.   The three-color, light projection system of claim 1, said first IBC

2 laser system further comprising:

3   a plurality of wavelength sources, wherein each wavelength source

4   of said plurality of wavelength sources comprises:

5   a plurality of VCSELs; and

6   a beam combining plate, wherein said beam combining

7   plate coherently sums emissions from said plurality of VCSELs;

8   an output coupler;

9   a wavelength dispersive element interposed between said plurality

10 of wavelength sources and said output coupler; and

11   a collimating means interposed between said plurality of

12 wavelength sources and said wavelength dispersive element.

1   13.   The three-color, light projection system of claim 1, said first IBC

2   laser system further comprising:

3   a first plurality of wavelength sources, wherein each wavelength

4   source of said first plurality of wavelength sources comprises:

5   a first plurality of VCSELs; and

6   a first beam combining plate, wherein said first beam

7   combining plate coherently sums emissions from said first plurality of

8   VCSELs;

9   a first output coupler;

10   a first wavelength dispersive element interposed between said first

11 plurality of wavelength sources and said first output coupler; and

12   a first collimating means interposed between said first plurality of

13 wavelength sources and said first wavelength dispersive element;

14 said second IBC laser system further comprising:

15   a second plurality of wavelength sources, wherein each wavelength

16 source of said second plurality of wavelength sources comprises:

17   a second plurality of VCSELs; and

18   a second beam combining plate, wherein said second beam

19 combining plate coherently sums emissions from said second plurality of

20 VCSELs;

21   a second output coupler;

22   a second wavelength dispersive element interposed between said

23 second plurality of wavelength sources and said second output coupler; and

16

24   a second collimating means interposed between said second

25   plurality of wavelength sources and said second wavelength dispersive element;

26   said third IBC laser system further comprising:

27   a third plurality of wavelength sources, wherein each wavelength

28   source of said third plurality of wavelength sources comprises:

29   a third plurality of VCSELs; and

30   a third beam combining plate, wherein said third beam

31   combining plate coherently sums emissions from said third plurality of

32   VCSELs;

33   a third output coupler;

34   a third wavelength dispersive element interposed between said

35   third plurality of wavelength sources and said third output coupler; and

36   a third collimating means interposed between said third plurality of

37   wavelength sources and said third wavelength dispersive element.

1   14.   The three-color, light projection system of claim 1, said first IBC

2   laser system further comprising:

3   a plurality of single transverse mode emitters;

4   a plurality of collimating optics with a collimating optic center-to-center

5   spacing equivalent to an emitter center-to-center spacing corresponding to said plurality

6   of emitters, wherein said plurality of collimating optics are adjacent to said plurality of

7   emitters;

8   a plurality of prisms with a prism center-to-center spacing equivalent to

9   said emitter center-to-center spacing corresponding to said plurality of emitters, wherein

10   said plurality of prisms are adjacent to said plurality of collimating optics;

11   a plurality of wavelength separating elements with a wavelength

12   separating element center-to-center spacing equivalent to said emitter center-to-center

13   spacing corresponding to said plurality of emitters, wherein said plurality of wavelength

14   separating elements are adjacent to said plurality of prisms;

15   a beam combining plate, wherein a plurality of emissions from said

16   plurality of emitters pass through said a plurality of collimating optics, through said

17   plurality of prisms, through said plurality of wavelength separating elements and are

18   incoherently combined within said beam combining plate; and

19   an output coupler.

1   15.   The three-color, light projection system of claim 1, said first IBC

2 . laser system further comprising:

3   a first plurality of single transverse mode emitters;

4   a first plurality of collimating optics with a collimating optic

5   center-to-center spacing equivalent to an emitter center-to-center spacing

6   corresponding to said first plurality of emitters, wherein said first plurality of

7   collimating optics are adjacent to said first plurality of emitters;

8   a first plurality of prisms with a prism center-to-center spacing

9   equivalent to said emitter center-to-center spacing corresponding to said first

10   plurality of emitters, wherein said first plurality of prisms are adjacent to said first

11   plurality of collimating optics;

12   a first plurality of wavelength separating elements with a

13   wavelength separating element center-to-center spacing equivalent to said emitter

14   center-to-center spacing corresponding to said first plurality of emitters, wherein

15   said first plurality of wavelength separating elements are adjacent to said first

16   plurality of prisms;

17   a first beam combining plate, wherein a first plurality of emissions

18   from said first plurality of emitters pass through said a first plurality of

19   collimating optics, through said first plurality of prisms, through said first

20   plurality of wavelength separating elements and are incoherently combined within

21   said first beam combining plate; and

22   a first output coupler;

23   said second IBC laser system comprising:

24   a second plurality of single transverse mode emitters;

25   a second plurality of collimating optics with a collimating optic

26   center-to-center spacing equivalent to an emitter center-to-center spacing

27   corresponding to said second plurality of emitters, wherein said second plurality

28   of collimating optics are adjacent to said second plurality of emitters;

29   a second plurality of prisms with a prism center-to-center spacing

30   equivalent to said emitter center-to-center spacing corresponding to said second

31   plurality of emitters, wherein said second plurality of prisms are adjacent to said

32   second plurality of collimating optics;

33   a second plurality of wavelength separating elements with a

34   wavelength separating element center-to-center spacing equivalent to said emitter

35   center-to-center spacing corresponding to said second plurality of emitters,

36   wherein said second plurality of wavelength separating elements are adjacent to

37   said second plurality of prisms;

38   a second beam combining plate, wherein a second plurality of

39   emissions from said second plurality of emitters pass through said a second

40   plurality of collimating optics, through said second plurality of prisms, through

41   said second plurality of wavelength separating elements and are incoherently

42   combined within said second beam combining plate; and

43   a second output coupler;

44   said third IBC laser system comprising:

45   a third plurality of single transverse mode emitters;

46   a third plurality of collimating optics with a collimating optic

47   center-to-center spacing equivalent to an emitter center-to-center spacing

48   corresponding to said third plurality of emitters, wherein said third plurality of

49   collimating optics are adjacent to said third plurality of emitters;

50   a third plurality of prisms with a prism center-to-center spacing

51   equivalent to said emitter center-to-center spacing corresponding to said third

52   plurality of emitters, wherein said third plurality of prisms are adjacent to said

53   third plurality of collimating optics;

54   a third plurality of wavelength separating elements with a

55   wavelength separating element center-to-center spacing equivalent to said emitter

56   center-to-center spacing corresponding to said third plurality of emitters, wherein

57   said third plurality of wavelength separating elements are adjacent to said third

58   plurality of prisms;

59   a third beam combining plate, wherein a third plurality of

60   emissions from said third plurality of emitters pass through said third plurality of

61   collimating optics, through said third plurality of prisms, through said third

62   plurality of wavelength separating elements and are incoherently combined within

63   said third beam combining plate; and

64   a third output coupler.

19

1   16.   The three-color, light projection system of claim 1, said first IBC

2   laser system further comprising:

3   a plurality of wavelength sources, wherein each wavelength source of said

4   plurality of wavelength sources comprises:

5   a plurality of VCSELs emitting a plurality of output beams; and

6   a first beam combining plate, wherein said first beam combining

7   plate coherently sums said plurality of output beams from said plurality of

8   VCSELs to form a single wavelength beam;

9   a plurality of collimating optics corresponding to said plurality of

10 wavelength sources;

11   a plurality of prisms corresponding to said plurality of collimating optics;

12   a plurality of wavelength separating elements corresponding to said

13 plurality of prisms;

14   a second beam combining plate, wherein each single wavelength beam of

15 said plurality of wavelength sources pass through a corresponding collimating optic of

16 said a plurality of collimating optics, pass through a corresponding prism of said plurality

17 of prisms, pass through a corresponding wavelength separating element of said plurality

18 of wavelength separating elements and are incoherently combined within said second

19 beam combining plate; and

20   an output coupler.

1   17.   The three-color, light projection system of claim 1, said first IBC

2   laser system further comprising:

3   a first plurality of wavelength sources, wherein each wavelength

4   source of said first plurality of wavelength sources comprises:

5   a first plurality of VCSELs; and

6   a first beam combining plate, wherein said first beam

7   combining plate coherently sums emissions from said first plurality of

8   VCSELs;

9   a first plurality of collimating optics corresponding to said first

10 plurality of wavelength sources;

11   a first plurality of prisms corresponding to said first plurality of

12 collimating optics;

13   a first plurality of wavelength separating elements corresponding to

14 said first plurality of prisms;

15   a second beam combining plate, wherein said second beam

16 combining plate incoherently combines emissions from said first plurality of

17 wavelength sources;

18   a first output coupler;

19   said second IBC laser system further comprising:

20   a second plurality of wavelength sources, wherein each wavelength

21 source of said second plurality of wavelength sources comprises:

22   a second plurality of VCSELs; and

23   a third beam combining plate, wherein said third beam

24 combining plate coherently sums emissions from said second plurality of

25 VCSELs;

26   a second plurality of collimating optics corresponding to said

27 second plurality of wavelength sources;

28   a second plurality of prisms corresponding to said second plurality

29 of collimating optics;

30   a second plurality of wavelength separating elements

31 corresponding to said second plurality of prisms;

32   a fourth beam combining plate, wherein said fourth beam

33 combining plate incoherently combines emissions from said second plurality of

34 wavelength sources;

35   a second output coupler;

36   said third IBC laser system further comprising:

37   a third plurality of wavelength sources, wherein each wavelength

38 source of said third plurality of wavelength sources comprises:

39   a third plurality of VCSELs; and

40   a fifth beam combining plate, wherein said fifth beam

41 combining plate coherently sums emissions from said third plurality of

42 VCSELs;

43   a third plurality of collimating optics corresponding to said third

44 plurality of wavelength sources;

45   a third plurality of prisms corresponding to said third plurality of

46 collimating optics;

21

47   a third plurality of wavelength separating elements corresponding

48   to said third plurality of prisms;

49   a sixth beam combining plate, wherein said sixth beam combining

50   plate incoherently combines emissions from said third plurality of wavelength

51   sources; and

52   a third output coupler.

1   18.   A three-color, light projection system, comprising:

2   a first plurality of gain elements;

3   a second plurality of gain elements;

4   a third plurality of gain elements, wherein each gain element of said first,

5   second and third pluralities of gain elements further comprises:

6   a back facet coated with an HR coating; and

7   a front facet coated with an AR coating;

8   an output coupler, wherein a first cavity is formed between said HR coated

9   back facets of said first plurality of gain elements and said output coupler, wherein a

10   second cavity is formed between said HR coated back facets of said second plurality of

11   gain elements and said output coupler, and wherein a third cavity is formed between said

12   HR coated back facets of said third plurality of gain elements and said output coupler;

13   a wavelength dispersive element interposed between said first plurality of

14   gain elements and said output coupler, wherein said wavelength dispersive element is

15   interposed between said second plurality of gain elements and said output coupler, and

16   wherein said wavelength dispersive element is interposed between said third plurality of

17   gain elements and said output coupler;

18   at least one collimating optic interposed between said first, second and

19   third pluralities of gain elements and said wavelength dispersive element;

20   a first means for modulating a first output corresponding to said first

21   cavity;

22   a second means for modulating a second output corresponding to said

23   second cavity;

24   a third means for modulating a third output corresponding to said third

25   cavity; and

26   a scanner for scanning said modulated first, second and third outputs.

22

1   19.   The three-color, light projection system of claim 18, wherein said

2   at least one collimating optic further comprises:

3   a first collimating optic interposed between said first plurality of gain

4   elements and said wavelength dispersive element;

5   a second collimating optic interposed between said second plurality of gain

6   elements and said wavelength dispersive element; and

7   a third collimating optic interposed between said third plurality of gain

8   elements and said wavelength dispersive element.

1   20.   The three-color, light projection system of claim 18, wherein said

2   at least one collimating optic is a reflective optic.

1   21.   The three-color, light projection system of claim 19, wherein said

2   first, second, and third collimating optics are reflective optics.

1   22.   The three-color, light projection system of claim 18, further

2   comprising:

3   a first divergence reducing means interposed between said first plurality of

4   gain elements and said at least one collimating optic;

5   a second divergence reducing means interposed between said second

6   plurality of gain elements and said at least one collimating optic; and

7   a third divergence reducing means interposed between said third plurality

8   of gain elements and said at least one collimating optic.

1   23.   The three-color, light projection system of claim 22, wherein said

2   first, second, and third divergence reducing means are selected from the group consisting

3   of cylindrical lenses, lens arrays, cylindrical lenses used in combination with lens arrays,

4   and aspheric lens arrays

1   24.   The three-color, light projection system of claim 22, wherein said

2   first divergence reducing means reduces a fast axis divergence corresponding to said first

3   plurality of gain elements to substantially match a slow axis divergence corresponding to

4   said first plurality of gain elements, wherein said second divergence reducing means

5   reduces a fast axis divergence corresponding to said second plurality of gain elements to

6   substantially match a slow axis divergence corresponding to said second plurality of gain

7   elements, and wherein said third divergence reducing means reduces a fast axis

8   divergence corresponding to said third plurality of gain elements to substantially match a

9   slow axis divergence corresponding to said third plurality of gain elements.

1   25.   The three-color, light projection system of claim 18, wherein said

2   first modulating means modulates a current corresponding to said first plurality of gain

3   elements, wherein said second modulating means modulates a current corresponding to

4   said second plurality of gain elements, and wherein said third modulating means

5   modulates a current corresponding to said third plurality of gain elements.

1   26.   The three-color, light projection system of claim 18, wherein said

2   first, second, and third pluralities of gain elements are selected from the group consisting

3   of edge emitting diodes, VCSELs, VECSELs, and diode-pumped solid-state lasers.

1   27.   A method of generating a display, comprising the steps of:

2   incoherently beam combining a first plurality of emissions from a first

3   plurality of laser sources to form a first color output beam;

4   modulating said first color output beam;

5   incoherently beam combining a second plurality of emissions from a

6   second plurality of laser sources to form a second color output beam;

7   modulating said second color output beam;

8   incoherently beam combining a third plurality of emissions from a third

9   plurality of laser sources to form a third color output beam;

10   modulating said third color output beam;

11   combining said modulated first, second and third color output beams to

12 form a modulated three-color output beam; and

13   scanning said modulated three-color output beam to generate the display.
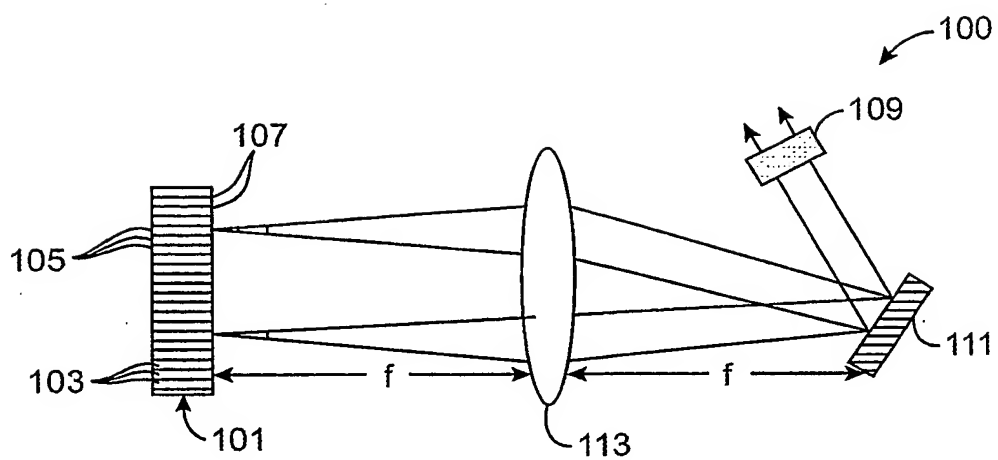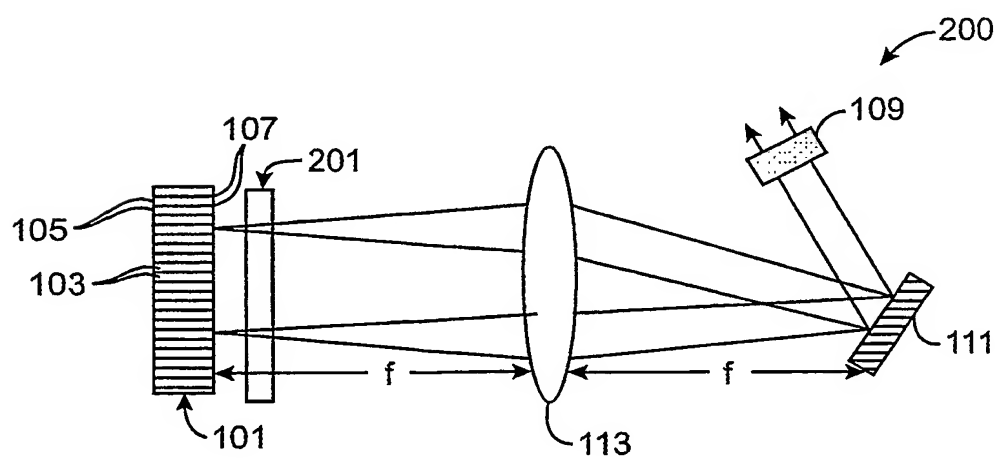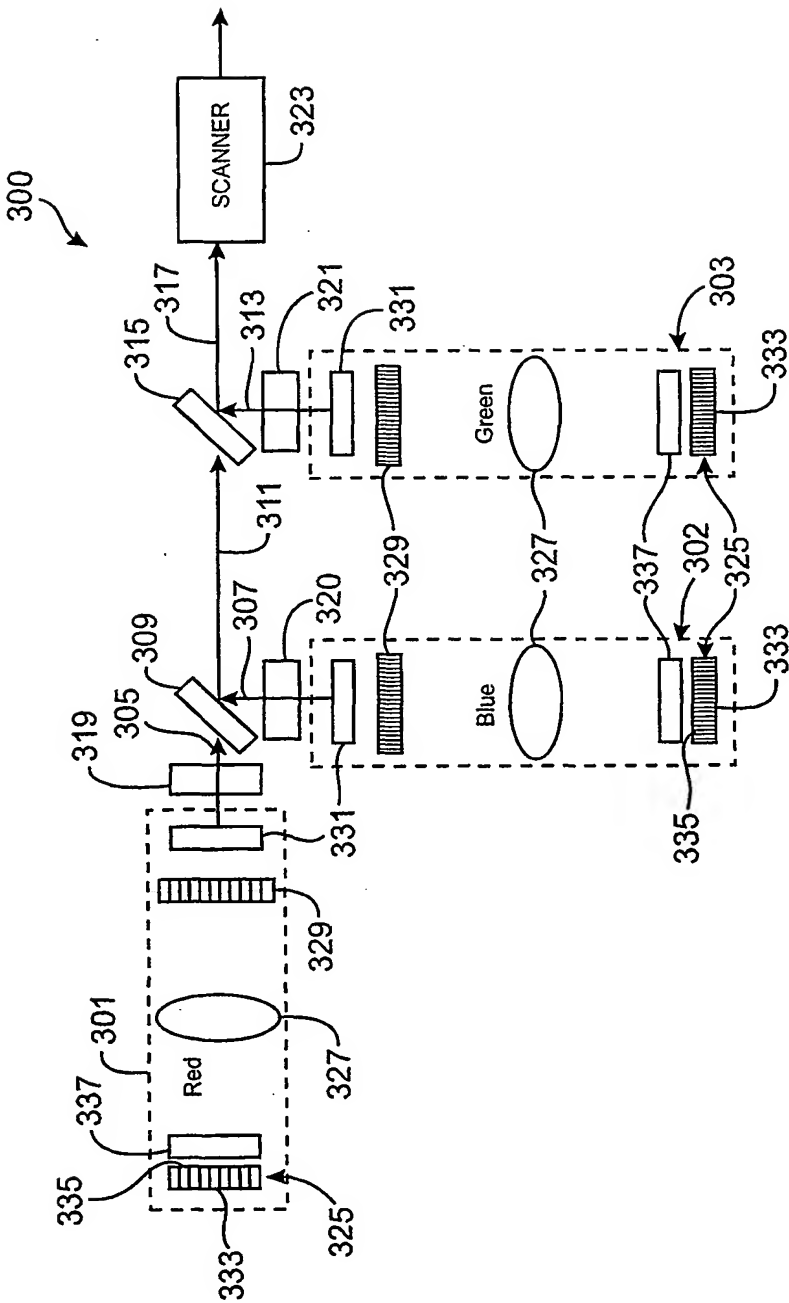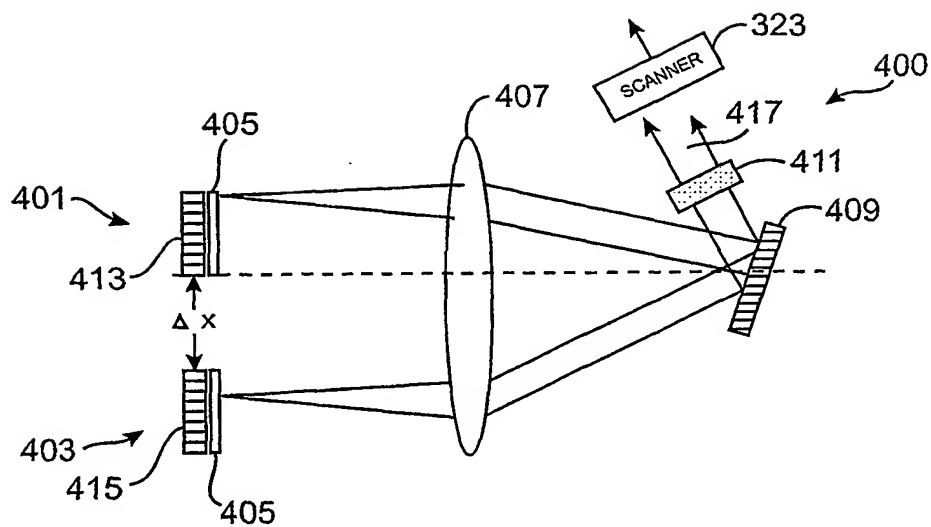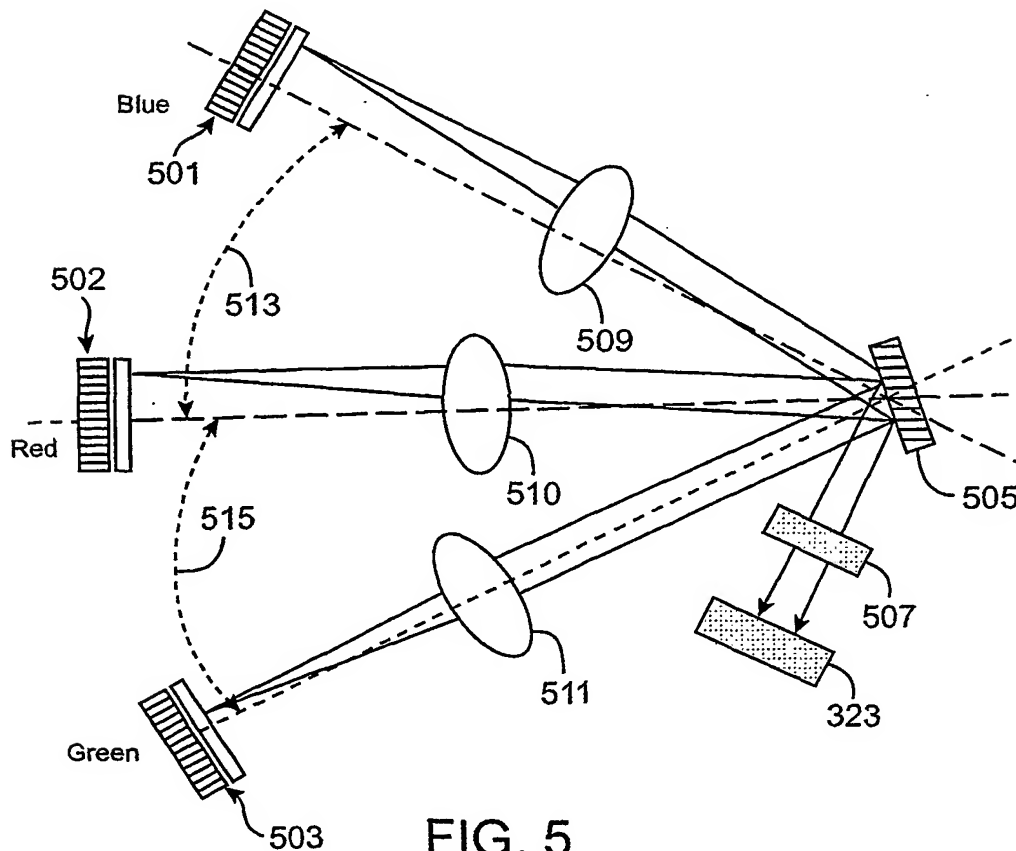
FIG. 1

FIG. 2

2 / 5

FIG. 3

FIG. 4

FIG. 5

4 / 5

FIG. 6

FIG. 7

800

805

λ_1

801   801   801   803
Optical or
electrical
pumping

FIG. 8

713

711

1   2   3   4....N

λ_1 λ_2 λ_3

800   800   800
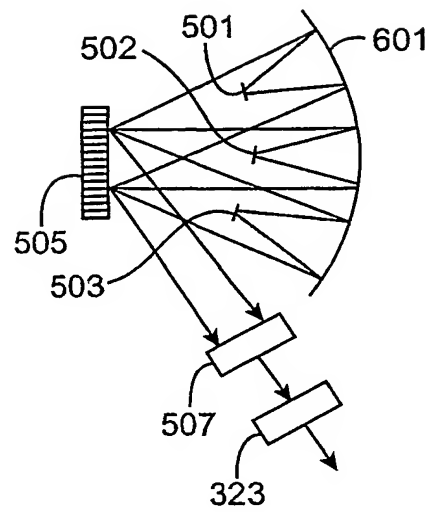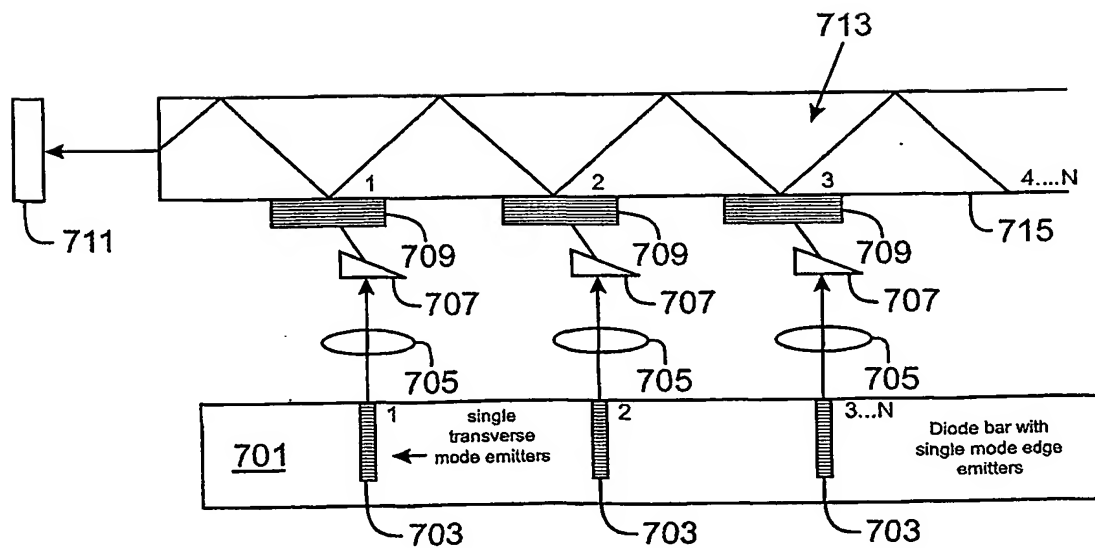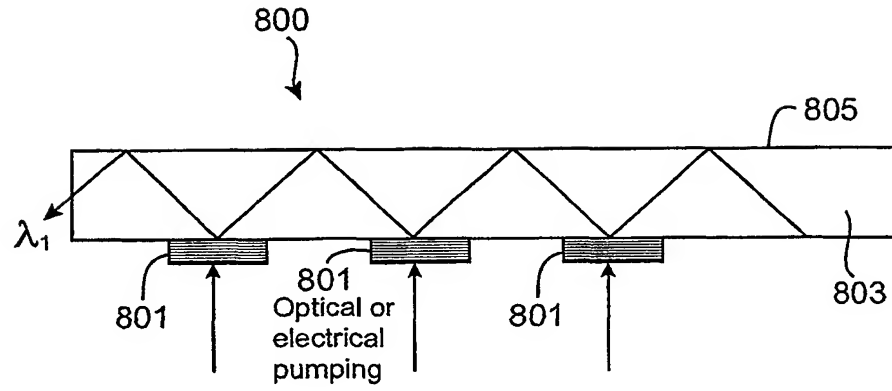
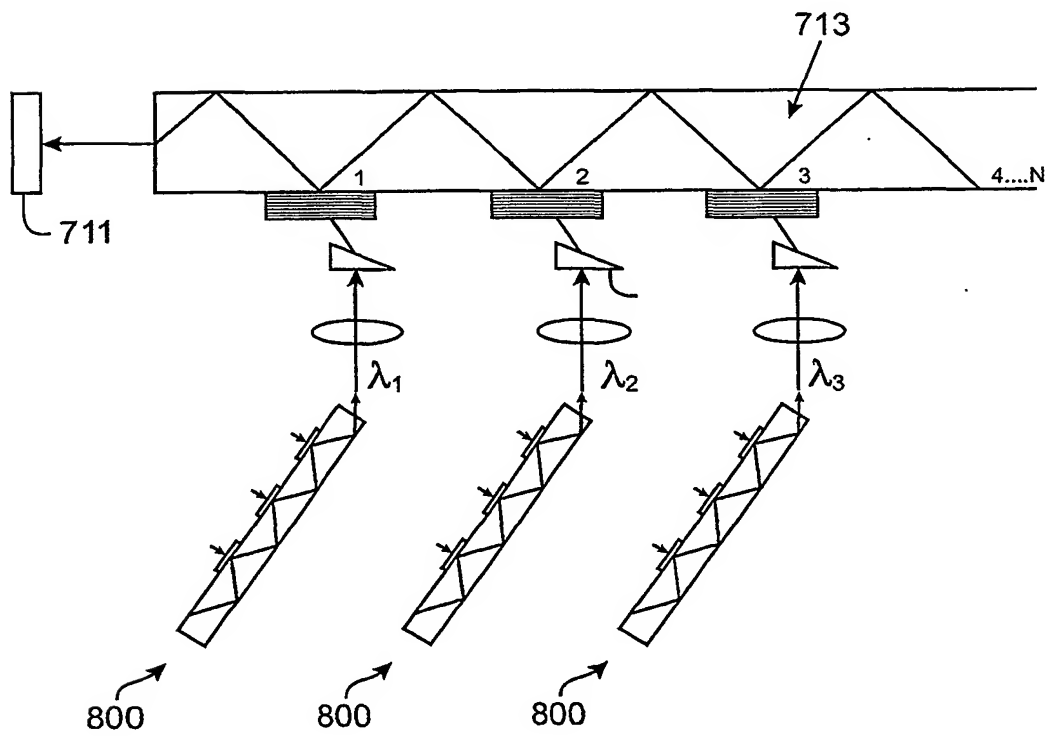# FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/14914

A.   CLASSIFICATION OF SUBJECT MATTER
IPC(7)   :   G03B 21/28: H04N 9/31
US CL   :   353/31: 348/757

According to International Patent Classification (IPC) or to both national classification and IPC

B.   FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 353/31, 34, 37: 348/750, 757; 359/204

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C.   DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US 6,304,237 B1 (KARAKAWA) 16 OCTOBER 2001 (16.10.2001) SEE ENTIRE DOCUMENT	1-27
A	US 4,978,202 A (YANG) 18 DECEMBER 1990 (18.12.1990) SEE ENTIRE DOCUMENT	1-27
A	US 4,833,528 A (KOBAYASHI) 23 MAY 1989 (23.05.1989) SEE ENTIRE DOCUMENT	1-27
A	US 5,485,225 A (DETER ET AL.) 16 JANUARY 1996 (16.01.1996) SEE ENTIRE DOCUMENT	1-27
A	US 5,317,348 A 31 MAY 1994 (31.05.1994) SEE ENTIRE DOCUMENT	1-27

☐   Further documents are listed in the continuation of Box C.   ☐   See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
20 August 2002 (20.08.2002)	11 SEP 2002

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